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(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 244 643 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 87104971.4

(22) Date of filing: 03.04.87

(51) Int. Cl.⁴: **B 41 J 3/04**

(30) Priority: 08.05.86 US 861192

(43) Date of publication of application: 11.11.87 Bulletin 87/46

(84) Designated Contracting States: DE FR GB IT

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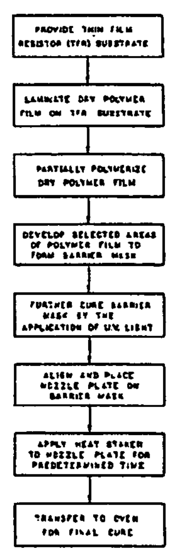
(54) Process for manufacturing thermal ink jet printheads and structures produced thereby.

(57) This invention is directed to a process for manufacturing thermal ink jet printheads wherein a polymer barrier layer is employed between a thin film resistor (TFR) substrate and a metal nozzle plate and serves as both the ink reservoir-defining material and the adhesive bonding mechanism for firmly securing these members one to another. The polymer barrier layer material is initially U.V. cured, then partially thermally cured in a heat staker and finally completely thermally cured in an oven. The surface contour of the barrier layer follows that of the nozzle plate and TFR substrate and thereby prevents any gaps from occurring in this composite structure. This feature in turn enhances the structural integrity of the printhead, enhances its lifetime and improves its frequency response. Repeatability of manufacturing and a more consistent drop volume ejection from printhead to printhead is also achieved.



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PROCESS FOR MANUFACTURING THERMAL INK JET PRINTHEADS AND STRUCTURES PRODUCED THEREBY

Technical Field

This invention relates generally to thermal ink jet (TIJ) printing and more particularly to a new and improved process for fabricating thermal ink jet printheads and printhead structures produced thereby.

Background Art

In the art of thermal ink jet printing, it is known to provide thin film resistor (TFR) type printheads for generating thermal energy which is applied or transfered to a plurality of ink reservoirs during an ink jet printing operation. Typically these reservoirs will be aligned with the individual heater resistors of the thin film resistor substrate. The printhead will typically include an underlying silicon substrate member upon which a thin passivation layer of silicon dioxide is deposited, and a resistor material such as tantalum aluminum is then deposited on the silicon dioxide layer to serve as the resistive heater

material for the device structure. Traces of a conductive material, such as aluminum, are then formed on the resistive layer in a predefined pattern which defines the length and the width of the individual resistive heater elements.

A protective inert barrier layer material, such as silicon carbide, is deposited atop the conductive pattern in order to protect the underlying materials from ink corrosion and cavitation wear. Such corrosion and wear is caused by the collapsing vapor bubble which would otherwise be transmitted from the ink reservoirs defined on top of the protective barrier layer in preestablished geometries. This type of structure is generally well known in the art and is described, for example, in the Hewlett-Packard Journal, Vol. 36, No. 5, May 1985, incorporated herein by reference.

In the past, one process for defining these ink reservoirs involved forming a pattern in a polymer film disposed on the surface of the silicon carbide barrier layer so as to define individual and separated reservoirs vertically aligned with the underlying resistive heater elements. Using this process, a photoresist polymer film was both ultraviolet (U. V.) and thermally cured on the surface of the inert barrier layer, and then a separate adhesive system was used to secure a nozzle plate to the top surface of the polymer film. Typical polymer materials suitable for this ink reservoir-defining film are sold by the Dupont Company of Wilmington, Delaware under the trade

names "RISTON" and " VACREL".

While the above process has proven generally satisfactory in many respects, there have nevertheless been observed flatness variations in both the nozzle plate and the barrier film. These flatness variations produce air gaps between these two members and the intermediate polymer layer using the above prior art process, and these air gaps may produce mechanical failure due to breakdown of the adhesive bond at these gaps. Furthermore, these gaps also reduce the frequency response of printhead operation. These air gaps are located across the surface of the printhead and cause an irregular volume of ink to be ejected therefrom, and the gaps also tend to interrupt or destroy the flow pattern of ink created by the third wall of the polymer barrier layer. This fact in turn shortens resistor life and increases cavitation damage. Additionally, the attachment of the nozzle plate, as mentioned above, required the utilization of a separate adhesive system.

Disclosure of Invention

The general purpose of this invention is to provide a new and improved TIJ printhead fabrication process and structure produced thereby which eliminates the above gaps between the polymer barrier layer and the nozzle plate attached thereto and accomplishes the same while simultaneously eliminating the need for a separate adhesive

system for attaching the nozzle plate to the polymer barrier layer defining the individual ink reservoirs.

To accomplish this purpose, we have discovered and developed a new and improved process which includes providing a thin film resistor (TFR) structure having a plurality of resistive heater elements therein, and thereafter forming an ultraviolet ("UV") cured (polymerized), but thermally uncured (ie no molecular cross-linking), pattern of photoresist on the upper surface of the thin film resistor structure. This photoresist polymer film is patterned to define a plurality of ink reservoirs disposed above the plurality of resistive heater elements, respectively. Then, a nozzle plate having a plurality of ink ejection orifices therein is aligned with the photoresist barrier layer, with the individual orifices in the nozzle plate being aligned with the ink reservoirs in the barrier layer.

Next, a predetermined amount of heat and pressure is applied via a heat staker or laminator to the nozzle plate to thereby produce a partial thermal curing of the photoresist barrier layer. This thermal curing produces excellent initial adhesion between the photoresist film and both the nozzle plate and the thin film resistor substrate structure, and the pressure applied to the structure during this process eliminates air gaps resulting from uneveness of adjacent layers . This curing eliminates air gaps

between the nozzle plate and the polymer film and it further eliminates the need for a separate adhesive material for securing the above adjacent members one to another. Finally, the printhead is removed from the heat staker and transferred to an oven where the thermal curing process is completed for a predetermined curing temperature and time.

The above advantages and features of this invention will become more readily apparent in the following description of the accompanying drawings.

Brief Description of Drawings

Figure 1 is a process flow chart indicating the individual process steps and sequence thereof utilized in a preferred process embodiment of the invention.

Figure 2 is a cross section view of a thin film resistor substructure which is typical of state-of-the-art multiple heater devices used in thermal ink jet printheads and particularly adapted for use in practicing the present invention.

Figures 3A through 3C illustrate the heat staking operation utilized in a preferred process embodiment of the invention.

Best Mode for Carrying Out the Invention

Referring now to Figure 1, there is shown an eight step process of carrying out the invention and includes the provision of a thin film resistor (TFR) substrate which has

been fabricated using state of the art semiconductor processing techniques. A dry polymer film is then laminated on the upper surface of the TFR substrate, and this upper surface will typically be an inert barrier layer of either SiC or Si_3N_4. This polymer film is then partially polymerized with UV light and selectively developed to form an ink reservoir barrier mask on the TFR substrate. Then the barrier mask is subjected to additional ultraviolet light to provide a further cure thereof.

Next, a nozzle plate (also referred to sometimes as an orifice plate) is aligned with and placed upon the barrier mask in preparation for a heat stake operation described in more detail below with reference to Figure 3. Finally, and after the completion of the heat stake operation, the printhead structure is transferred to an oven for final curing at a predetermined time and elevated temperature.

Referring now to Figure 2, a thin film resistor structure which may be used in carrying out the present invention will typically consist of a silicon substrate member 10 upon which a thin silicon dioxide ,Si02, surface barrier layer 12 is deposited using known thermal oxidation techniques. Then, a resistive layer 14 of tantalum aluminum, TaA1, is sputtered deposited on top of the Si02 barrier layer 12, and thereafter a metalization pattern 16 which will typically be aluminum is formed as shown on the

surface of the tantalum aluminum layer 14. The metalization pattern 16 will have openings therein defining the lateral dimensions of the individual resistors in the TFR structure.

Next, another, outer surface passivation layer 18 is deposited on the outer surface of the conductive pattern 16 and will typically consist of either silicon carbide, SiC, or silicon nitride, Si_3N_4. These latter materials are highly inert and are thus protective of the underlying materials from both ink corrosion and cavitation wear produced by the ink and ink ejections respectively during a thermal ink jet printing operation. The processing details used in producing a thin film resistor substrate structure of the type shown in Figure 2 are generally well known to those skilled in this art and more fully described in the above identified Hewlett-Packard Journal published May 1985 and incorporated herein by reference.

Referring now to Figure 3A through 3C, the TFR substrate of Figure 2 is illustrated only schematically as a single member in Figure 3A without showing the individual layers therein. However, Figures 3A - 3C still show the location of the four tantalum-aluminum heater resistors 20 which are subsequently aligned with the openings 22 in the polymer ink reservoir barrier layer 24. This barrier layer 24 is laminated on the TFR substrate 10 as a dry film of a material such as VACREL or RISTON which are trade names of

photoresist polymer materials commercially available from the Dupont Company of Wilmington, Delaware. Thus, the polymer film 24 is processed using conventional photolithographic masking, ultraviolet exposure and etching techniques in order to form the plurality of openings 22 therein which define the boundaries of four individual ink reservoirs. These reservoirs are disposed immediately above the four resistive heater elements 20 of the thin film substrate 10 which supports it. Once the barrier layer 24 is developed to remove the unwanted selected portions of the dry film and create openings 22 therein, the structure of Figure 3A is exposed to some additional ultraviolet light to further UV cure the barrier layer 24 in accordance with the processing detail given below.

In Figure 3B, an orifice or nozzle plate 26 having a plurality of openings 28 therein is aligned on the barrier layer 24 as shown, so that the orifices 28 are precisely centered with the ink reservoirs 22 in the barrier layer 24. With the nozzle plate 26 thus in place, a hot chuck 30 of a heat staker apparatus is moved down into thermal and pressure contact with the top surface of the nozzle plate 26 and held there at a predetermined pressure and for a predetermined time to partially thermally cure the barrier layer material 24. This step provides a good initial interface adherance and good surface contour match at the barrier layer-nozzle plate interface, as well as at the barrier

layer-TFR substrate interface.

The hot chuck 30 of the heat staker is brought into contact with the nozzle plate 28 under sufficient pressure to allow the barrier material 24 to plastically deform and adhere and conform to the contour of the upper surface of the nozzle plate 28. Then, the chuck 30 is released and the ink jet printhead of Figure 3C is transferred to a hot oven to fully cure the dry barrier film 24 in accordance with the processing schedule below.

The present invention allows batch processing of parts during a nozzle plate attachment operation and thereby results in quick bonding of the nozzle plate 26 to the barrier layer 24 as indicated. This process deforms the dry film barrier layer 24 into the shape of the nozzle plate 28 to thereby fill any gaps therein, and in addition, further prevents the printhead substrate 10 from overheating during the nozzle plate attachment process. Furthermore, this process allows the batch processing of parts without the requirement for clamping, which has been a frequent requirement in prior dry film-adhesive cures. And, as mentioned above, the present process eliminates the need for separate adhesives and adhesive bonding operations during the assembly process. Finally, the present process imparts long lasting structural integrity to the printhead structures being fabricated and insures permanent (plastic) deformation

of the dry film barrier layer material.

Various modifications may be made to the above described process without departing from the scope of the present invention. For example, the barrier layer materials are not limited to the particular VACREL and RISTON polymers sold by the Dupont Company and may instead employ other suitable polymer materials.

The following table of values includes those processing parameters which have been used successfully in the reduction to practice of the present invention.

TABLE

1. INERT PROTECTIVE LAYER OF TFR SUBSTRATE
   - MATERIAL . . . . S_1C or Si_3N_4
   - THICKNESS . . . . 1.5 - 2.0 micrometers
2. POLYMER BARRIER LAYER
   - MATERIAL . . . . Vacrel 8015/Vacrel 8020
   - THICKNESS . . . . 1.5 mil/2.0 mil
3. NOZZLE PLATE
   - MATERIAL . . . . Gold over Nickel
   - THICKNESS . . . . 50 micrometers
4. ULTRAVIOLET (UV) CURE
   - CURING ENERGY . . . . 5 $Joules/cm^2$
   - UV WAVELENGTH . . . . 365 nanometers
5. HEAT STAKER CURE
   - CURING TIME . . . . . . 16 seconds
   - CURING TEMPERATURE . . 160^oC

CURING PRESSURE . . . 200 psi

6. OVEN CURE

TIME . . . . 1 hour

TEMPERATURE . . . . . $165^{o}C$

Industrial Applicability

The present invention is useful in the manufacture of thin film resistor type printheads used in thermal ink jet printers.

Claims

1. A process for bonding a nozzle plate in place with respect to a printhead substrate which comprises:

a. forming a polymer barrier layer which is not fully thermally cured on the surface of said substrate,

b. aligning and placing a nozzle plate on the surface of said barrier layer,

c. applying measured heat and pressure to said nozzle plate for a predetermined time and temperature sufficient to cause said barrier layer to deform and conform to contours in said nozzle plate, and

d. further heating said substrate, barrier layer and nozzle plate at a predetermined elevated temperature to thermally cure said barrier layer, whereby said barrier layer is firmly secured to said substrate and nozzle plate without the requirement for separate adhesives and adhesive bonding operations.

2. A process for fabricating a thermal ink jet printhead comprising:

a. providing a thin film resistor structure having a plurality of resistive heater elements therein,

b. forming a pattern in a UV cured but thermally uncured or at least partially thermally uncured pattern in a polymer film on the upper surface of said

thin film resistor structure to define a plurality of ink reservoirs disposed above said plurality of resistive heater elements, respectively,

c. aligning orifices of a nozzle plate with said ink reservoirs and placing said nozzle plate on the top surface of said barrier layer,

d. applying a predetermined heat and pressure to said nozzle plate to cause said barrier layer to deform and conform to surface contours in said nozzle plate, and

e. further thermally curing said barrier layer at a predetermined elevated temperature and for a predetermined time sufficient to fully cure said barrier layer and produce good adhesion between said barrier layer and both said nozzle plate and said thin film resistor structure, whereby said process requires no individual adhesive or glueing steps.

3. A process for bonding a nozzle plate to a printhead substrate which includes the steps of:

a. providing a polymer barrier layer material which is not fully cured thermally between and in intimate contact with aligned major facing surfaces of said substrate and nozzle plate, and

b. thermally curing said barrier layer under conditions of predetermined heat and pressure and for a

predetermined time sufficient to produce a good adhesive bond between said barrier layer and both said substrate and nozzle plate.

4. The invention defined in claim 3 wherein the thermal cure of said barrier layer is achieved in a two step process of first exposing said composite substrate-barrier layer-nozzle plate structure to predetermined heat and pressure to produce partial thermal curing of said barrier layer and plastic deformation thereof and initial adherance to both said nozzle plate and said substrate, and secondly heating said composite structure at a further elevated temperature and for a time sufficient to fully thermally cure said barrier layer and also to produce optimum adherance to said substrate and to said nozzle plate.

5. A composite thin film resistor substrate - barrier layer - nozzle plate structure which is manufactured by the steps of:

a. providing a thermally uncured or at least partially thermally uncured polymer barrier layer material between and in intimate contact with aligned major facing surfaces of said substrate and nozzle plate, and

b. thermally curing said barrier layer under conditions of predetermined heat and pressure and for a predetermined time sufficient to produce a good

adhesive bond between said barrier layer and both said substrate and nozzle plate.

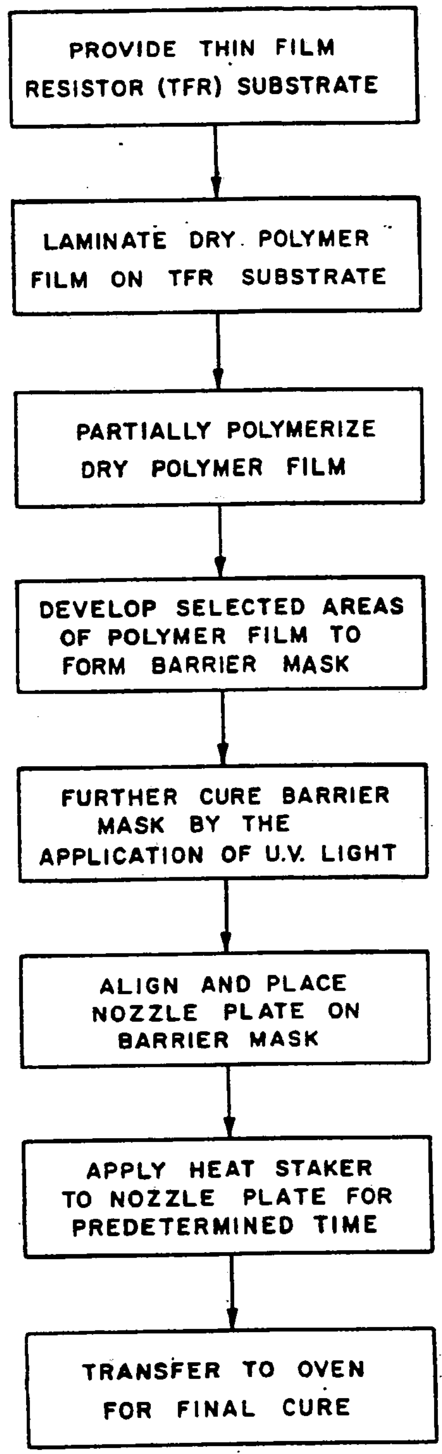
PROVIDE THIN FILM RESISTOR (TFR) SUBSTRATE
LAMINATE DRY POLYMER FILM ON TFR SUBSTRATE
PARTIALLY POLYMERIZE DRY POLYMER FILM
DEVELOP SELECTED AREAS OF POLYMER FILM TO FORM BARRIER MASK
FURTHER CURE BARRIER MASK BY THE APPLICATION OF U.V. LIGHT
ALIGN AND PLACE NOZZLE PLATE ON BARRIER MASK
APPLY HEAT STAKER TO NOZZLE PLATE FOR PREDETERMINED TIME
TRANSFER TO OVEN FOR FINAL CURE

Fig. 1

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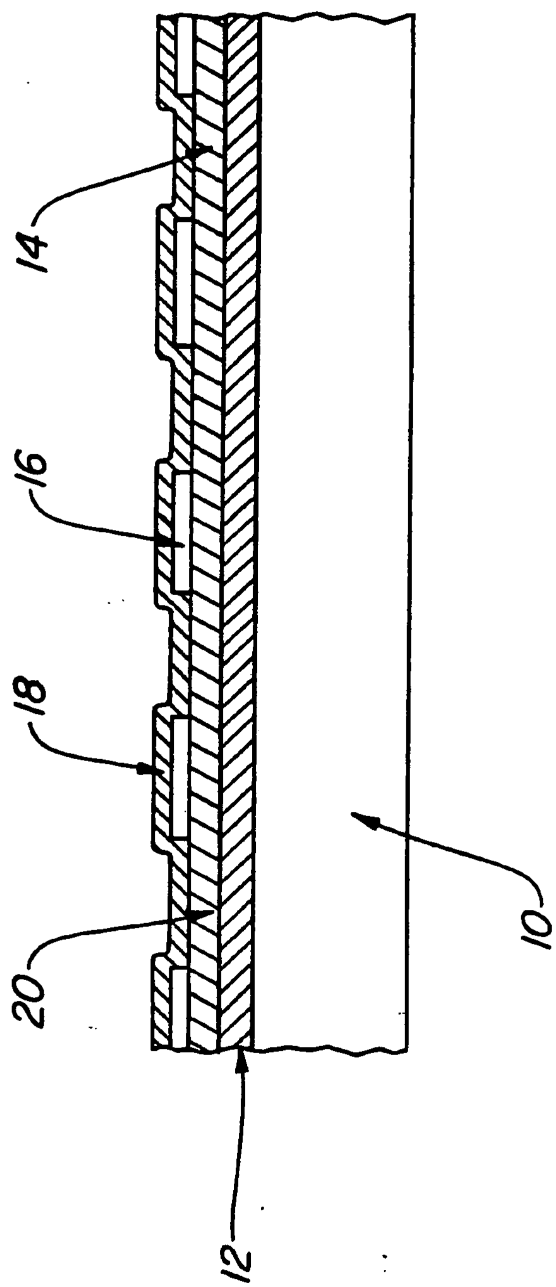

Fig. 2

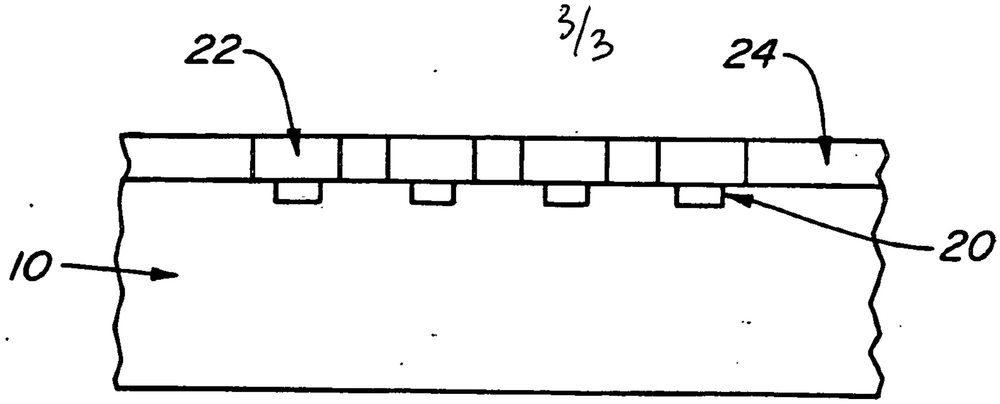

Fig. 3A

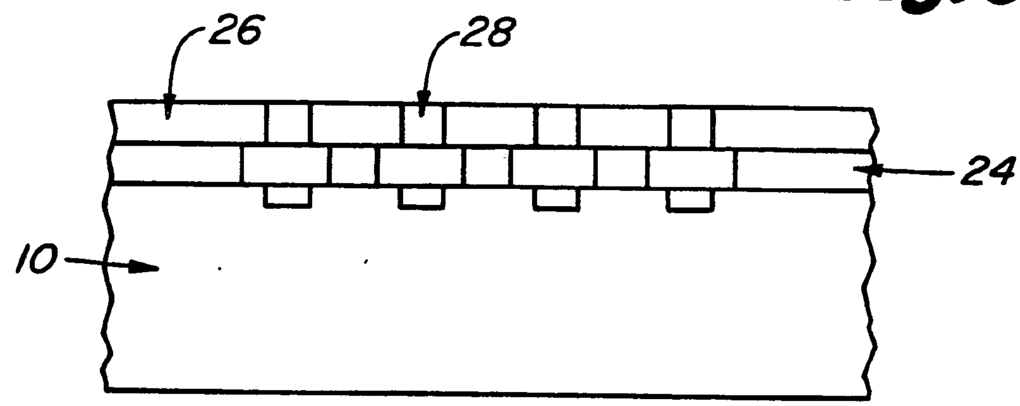

Fig. 3B

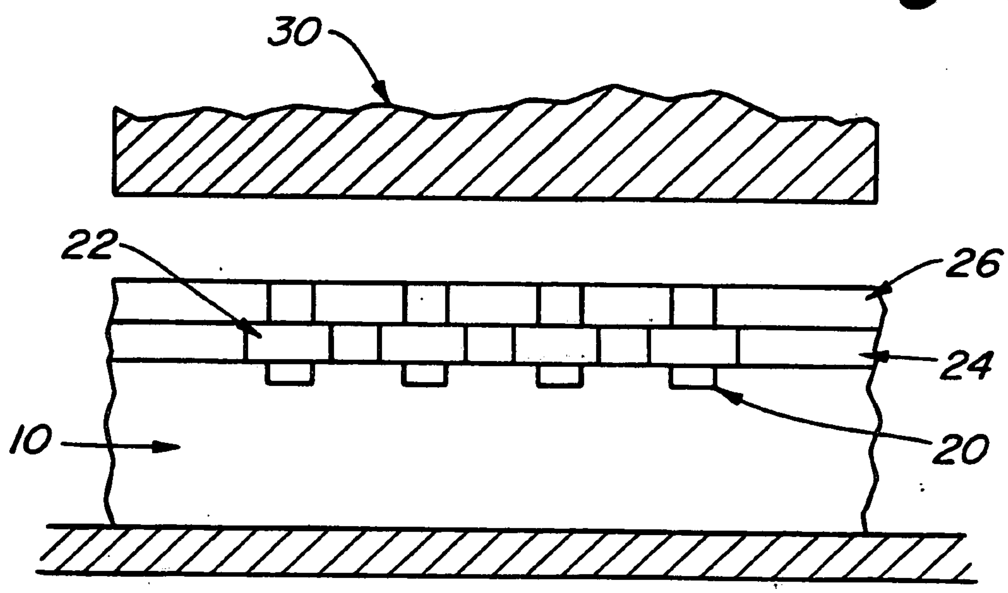

Fig. 3C